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STUDIES IN THE NEOCENE OF CALIFORNIA.[1]

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INTRODUCTION.

THE Santa Cruz Mountains, one of the Coast Ranges, lie just south of the city of San Francisco, and occupy a region about sixty-five miles long by twenty-five wide as a maximum. The whole region is an intricate series of ridges and narrow, deep valleys. The highest points rise nearly 4000 feet. The main axis has a northwest and southeast trend, and as the coast here lies nearly north and south, the ocean has cut a diagonal cross-section of its northern end, giving an excellent opportunity for the study of its history.

GENERAL GEOLOGY.

All around the edge of the mountains are nearly level plains formed partly by erosion, partly by the deposition of horizontal, unconsolidated Quaternary deposits.

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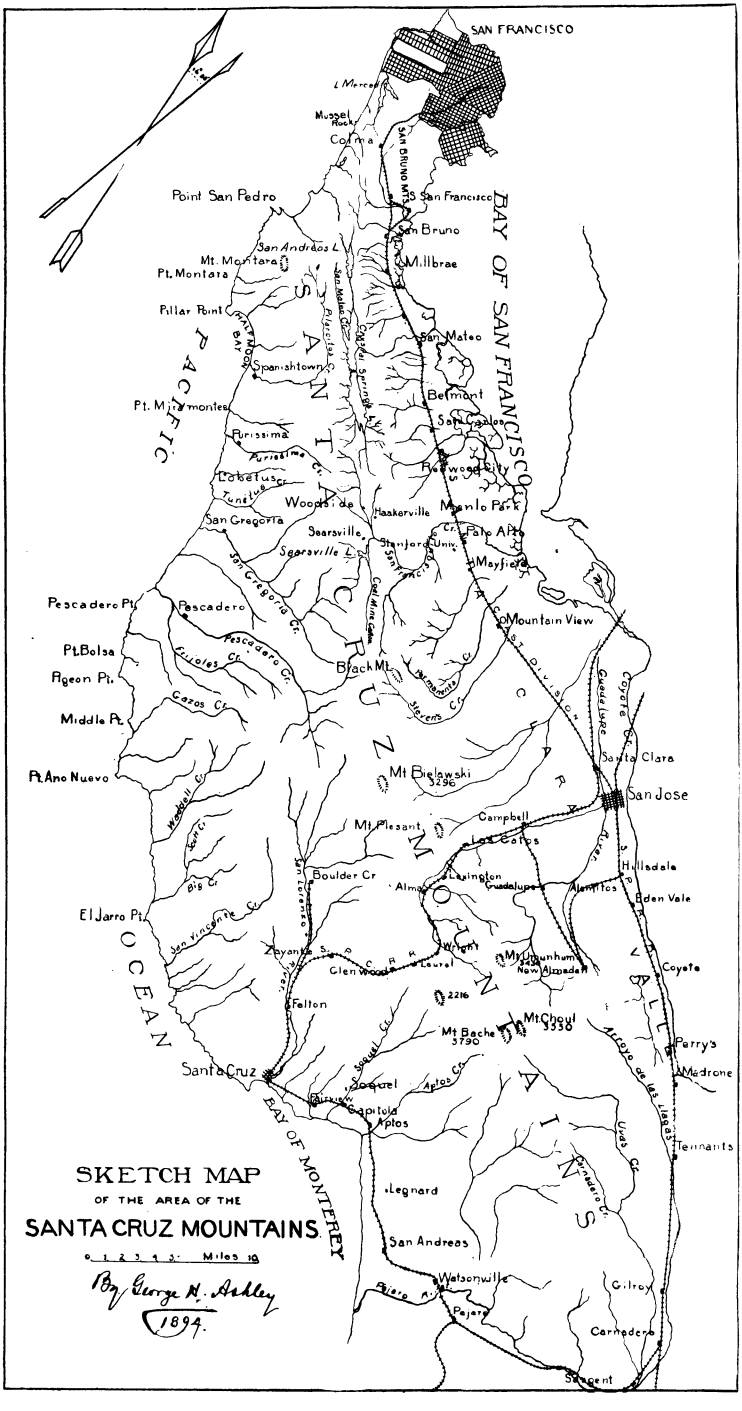
[1] Abstract of a paper presented at Leland Stanford Junior University for the degree of Doctor of Philosophy.



SKETCH MAP
OF THE AREA OF THE
SANTA CRUZ MOUNTAINS

By George H. Ashley
1894.

Unconformably below these deposits lies a series of sandy and clayey strata, partly consolidated, having locally a thickness of nearly a mile. This series, called recently by Professor Lawson[1] the Merced series, has been gently folded and has now been largely removed from the higher parts of the range. It is quite fossiliferous, and exhibits an interesting life history. In age it is mainly Pliocene, but appears to run into the Pleistocene above, and into the Miocene below.

Conformably below the Merced series is the Monterey series, one of the earliest of California formations to be studied and described. It is a great thickness of light-colored, bituminous shale, containing few fossils, and similar in structure to the Merced series. It is of Miocene age.

Unconformably below the preceding series, and having considerable prominence in the Santa Cruz Mountains, is a great series of sandstones, shales, and conglomerates, which we propose to call the Pescadero series. They consist in part of the San Francisco sandstone of previous writers. The section near Pescadero gives a questionable thickness of over 10,000 feet. They have been greatly disturbed and faulted. Their age has been shown to be in part Miocene, and is thought to extend down through the Eocene and possibly into the Cretaceous.

Still more prominent about San Francisco and through the Santa Cruz Mountains is a group of metamorphic and igneous rocks. They are cherts, sandstones, limestone, granite, serpentine, etc. They might be grouped together as the pre-Tertiary rocks of the Coast Ranges.

A small amount of Tertiary igneous rock occurs in the Santa Cruz Range.

STRATIGRAPHY.

Below is given a columnar section of the Santa Cruz Mountains. The formations there given will be briefly described, beginning with the oldest.

The metamorphics.—Under the term metamorphics may be included the beds of limestone occurring through the mountains, the granite forming the core of the range, the metamorphic sandstone, the thin-bedded chert, and the serpentine.

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[1] Univ. of Cal., Bull. Dept. of Geol., I., 143

The limestone, whose age is unknown, occurs in two beds, extending southward from near Point San Pedro.

COLUMNAR SECTION OF THE SANTA CRUZ MOUNTAINS.

Pleistocene		Subaërial deposits. Marine deposits. Subaërial deposits.	*Elephas*, conifers.	Thickness 2000 + ft.
Pliocene	Merced Ser.	Fossiliferous beds of sandstone, shale, and conglomerate. Transitional from the Miocene. to the Pleistocene.	Living shells *Mactra* (not *Venus*) *pajaroensis.* Large *Pectens*, *Arcas*, etc. Cetacean bones.	Pescadero Ser. 4700 + ft.
Miocene	Monterey Ser.	Bituminous or White Miocene shale; with some sandstone.	Infusoria. *Pecten peckhami*, *Tellina congesta.*	Thickness 1000 ft.
Eocene?	Thickness	Sandstones and conglomerates; Carmelo series (?) Pescadero sandstones and shales.	*Turritella hoffmanni.* *Ostrea titan.* *Liropecten estrellanus.* *Dosinia*, etc.	Thickness 2000 to 10,000 ft.?
Cretaceous?		The "San Francisco sandstone" (in part). Aucella beds.	Plant remains. *Inoceramus.* *Aucella.*	Thickness ?
Pre-Cretaceous		Radiolarian chert or phthanite. Metamorphic sandstone. Gavilan limestone.	Radiolaria. Foraminifera.	Thickness ?

It is usually highly crystalline, and, though of great thickness, is not prominent in the mountains.

The granite appears prominently in only two ridges; from Point San Pedro southward a few miles, and from Santa Cruz to Pescadero Creek. Occasional outcrops, however, show that it has considerable body under the main ridge. It is thought to be younger than the limestone and the other metamorphics. The cherts have been described by Mr. Becker under the name of phthanites,[1] and more recently by Mr. F. Leslie Ransome as radiolarian cherts.[2] They are usually dark brown, thin bedded, much contorted siliceous rocks, very characteristic wherever found in the Coast Ranges. The only fossils thus far found in them are *Radiolaria*, and these have led to the belief that the rocks are of Jurassic or Cretaceous age. In connection with the radiolarian chert there frequently occurs a metamorphic sandstone, ranging in color from light yellow to dark brown. It usually shows evidence of having been subjected to agencies which have obliterated nearly all bedding planes, produced secondary silicification, and frequently reduced the whole to a structureless mass.

In various parts of the range are considerable areas of serpentine and kindred rocks. The origin of this serpentine has been the subject of much discussion. There can now be no doubt but that it is a decomposition product of peridotes and other igneous rocks with which it is associated.

The relation of the metamorphic rocks to each other and to the younger rocks is very obscure, and the subject will not be taken up here.

THE PESCADERO SERIES.

The San Francisco sandstone was one of the earliest formations recognized and described in California. By Professor Blake it was assigned to the Tertiary.[3] It was later found that the fossils upon which his conclusions were principally based came from the Pliocene of the Merced series. Professor Whitney called the formation Cretaceous, classing the metamorphic rocks with it.[4] Recent writers have thought the metamorphics and San Francisco sandstone pre-Cretaceous.[5] The writer has been able to verify Professor Blake's first conclusion. The sandstone has been traced from outcrop to outcrop from San Francisco, through the San Bruno Mountains to Point San Pedro, and down to Pescadero where there is for about four miles a continuous exposure of the series with a perpendicular dip. At one end of this series were found characteristic Miocene fossils, such as *Turritella hoffmanni.* This clue was then followed back into the mountains to other localities yielding a more abundant fauna from which may be mentioned *Ostrea titan* and *Liropecten estrellanus.*

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[1] Monograph XIII., U. S. Geol. Sur., 1888.

[2] Univ. of Cal., Bull. Dept. Geol., I., 199–200.

[3] Rep. Geol. Recon. of Cal., 1858, p. 153.

[4] Geol. Surv. of Cal., Geology, I., 77, 24, etc.

[5] American Geologist, IV., March, 1892, 133.

Having thus shown that a part at least of what has been known as the San Francisco sandstone is of Miocene age, it is believed that most, if not all, of those localities from which *Ostrea titan* and the associated fauna have been reported will be found to show the presence of the Pescadero series.

In Bear Creek Valley near Haakerville fucoids occur in a light-colored sandstone. Mr. Gabb correlates these rocks with what has since been shown to be Tejon (Eocene) in the Monte Diablo region. As the strata near Haakerville are believed to form part of the Pescadero series, some evidence is thus afforded that the Pescadero series is in part of Tejon age.

In the head waters of Stevens' Creek, and in Alum Rock Canyon in the Mount Hamilton Range near San Jose, are found the fossiliferous strata of the Pescadero series.

Lithology and stratigraphy.—The Pescadero rocks may be described under three facies, the first two of which everywhere grade into each other, the last being more distinct.

The first is typically developed at Point San Pedro. The exposure there consists of dark and black shales and shaly sandstones which, while showing finer bedding, are distinctly bedded in layers of one to three inches or more in thickness. These beds weather into soft yellow layers. This facies is well exposed in San Francisco in the deep cut on Second street. The second facies is the sandstone described by Whitney as the San Francisco sandstone; a heavy-bedded sandstone, yellow or brown where weathered, but a dark gray blue where freshly exposed. In places the beds are a foot or two in thickness, and the stratification is distinct. In other places the strata are heavily bedded and frequently so intersected with joint planes that it is difficult to make out the real bedding.

These two facies were not found occupying definite horizons, but, as in the Pescadero section, grade into each other irregularly in the vertical section.

The third facies is more characteristic. It is hard, brown or dark colored conglomerate, heavy bedded, the pebbles of metamorphic rock are from one to four inches in diameter, and are sometimes distinctly faulted.

The Pescadero section gave a questionable thickness of over 10,000 feet. The exposure is cut off on the north by a nonconformity, and on the south by a fault. The conglomerates at the top or south end of the section have a thickness of 720 feet. It is thought that the Carmelo series of Professor Lawson[1] may be only a local development of the conglomeratic facies.

Occurrence.—The Pescadero series is well exposed at Benicia; in the northeastern quarter of San Francisco; in the San Bruno Mountains, and all through the Santa Cruz, Mount Hamilton and Monte Diablo Ranges. It will probably be found to be widespread throughout the Coast Ranges.

Relations.—No evidence of nonconformity between the Pescadero series and the metamorphic sandstone and phthanite was found, although one probably exists. The lowest Eocene and the uppermost Cretaceous are, as yet, unknown in California, and in the southern part of the state Chico beds lie unconformably on Knoxville, showing the absence of Horsetown strata.

THE MONTEREY-MERCED PERIOD.

The Monterey series was long ago described and assigned to the Miocene, and later investigations have not modified that decision.

The Merced series was first mentioned by Whitney, who merely speaks of the finding of Pliocene strata on Seven Mile Beach[2] by Gabb and Remond. Until recently these beds seem to have commanded but little attention. They were recently described more in detail by Professor Lawson, by whom they were called the Merced series.[1] They have been called Pliocene by all who have worked on them. From Half Moon Bay southward at a number of places occur very fossiliferous beds which have often been referred to, but of which very little has been written. The fossils obtained from these beds have been referred by some to the Miocene, by others to the Pliocene. The same beds have been referred to the Pliocene where little disturbed, and to the Miocene where much disturbed.

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[1] Univ. of Cal., Bull. Dept. Geol., Vol. I., p. 19.

[2] Geol. Surv. of Cal., Geology, I., 79.

The field-work of the writer has shown:

1. That, though minor oscillations have occurred, there was continuous sedimentation from the beginning of the Monterey period to the end of the Merced.

2. That the two series are similar in structure, that structure having been determined by the movement which took place at the end of the Merced period.

3. That the fossiliferous beds south of Half Moon Bay are conformable with the Monterey series below them and with the Merced series above them.

4. That the Monterey series is Miocene; that the Merced series on Seven Mile Beach is principally Pliocene, and that the fossiliferous beds, transitional between the two, contain a mixture of Miocene and Pliocene forms. In other words if a line were drawn between the Miocene and the Pliocene it would not come at the top of the Monterey series, as usually defined, but from one hundred to several hundred feet higher—somewhere in the fossiliferous beds.

It would be difficult, if not impossible, to draw the line between the two ages, as it would be largely governed by individual inclinations. Accordingly the writer prefers simply to call them the Transition beds of the Merced series, grouping them with the Merced series because lithologically they are similar to the predominating rocks of that series.

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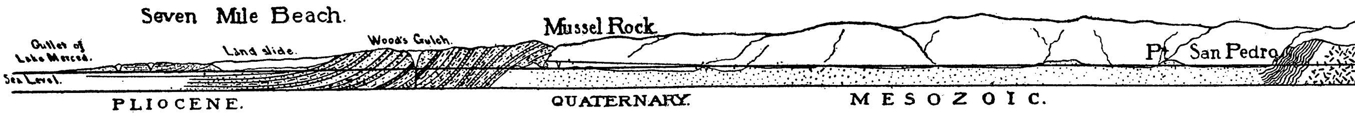
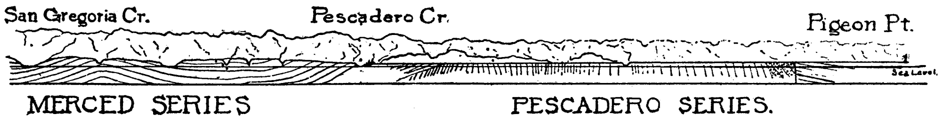
[1] Univ. of Cal., Bull. Dept. of Geol., I., 143.



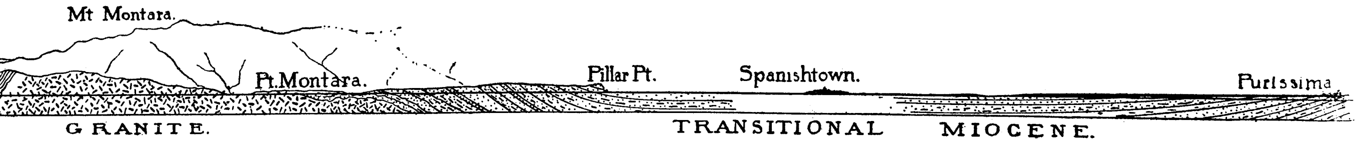
Section from Lake Merced to Purissima, 23¼ mi



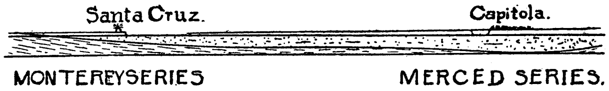
Section from San Gregorio to Pigeon Point, 8 miles.

Vertical scale twice the horizontal scale.

Plate IX.



¼ miles. Vertical scale twice the horizontal scale.



Section from Santa Cruz to Capitola, 5 miles.

Vertical scale twice the horizontal scale.

THE MONTEREY SERIES.

Lithology.—The rocks of the Monterey series are for the most part of a nearly white or light buff color, soft and porous, without grit, yet resisting weathering in a remarkable manner. They are usually quite thin-bedded, the bedding being very distinct. The porosity has been found in some cases to be due to the leaching-out of minute shells, probably those of foraminifera. Usually bituminous, they are locally like a coarse-grained sandstone in which the matrix is bitumen. In places they are silicified into chert. At Monterey and other places they are rich in infusorial forms, diatoms, sponges, etc., so that the beds have been considered a vast deposit of such forms. Recently Professor Lawson has advanced the idea that the White shale is of volcanic origin.[1] It is difficult on that theory to account for its occasional presence in the Merced series. The series has a thickness of about 1000 feet.

Occurrence.—The Monterey series is practically lacking on the northeastern side of the Santa Cruz Mountains. It is abundant all over the southwestern side from Spanishtown southward, and in fact all through the ranges to the south down into southern California, while similar strata have been found as far north as Oregon.

Relations.—The Monterey series, though containing but few fossils, has been recognized from the first as Miocene. Characteristic fossils are *Pecten peckhami*, Gabb ; *Tellina congesta*, Conrad ; *Meretrix traskii*, Conrad ; *Mercenaria perlaminosa*, Conrad. A comparison of the structure alone is sufficient to show that it lies unconformably upon the older rocks.

THE MERCED SERIES.

The Merced series is of considerable thickness, and is quite fossiliferous. Its location is very favorable for the exposure of fine sections, so that along the seaboard it is exposed almost continuously the whole length of the Santa Cruz Mountains and in cliffs averaging perhaps seventy-five feet high, but on Seven Mile Beach becoming over 700 feet high. (See Plate IX.)

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[1] Univ. of Cal., Bull. Dept. Geol., I., 24.

Lithology.—The Merced series of the Santa Cruz Mountains is composed of a great thickness of partly consolidated sands, clays, argillaceous sands and hard fine conglomerates. The most abundant and characteristic rock is a dark drab or slate-colored argillaceous sand, breaking into small fragments of about half an inch cube, frequently with bright red or yellow faces. It varies in hardness from that which crushes easily in the hand to more argillaceous varieties which are tough like clay. A soft yellow or buff-colored sand is quite common, and along Seven Mile Beach there are many thin layers of hard conglomerate, usually containing many fragments of shells. Occasionally shells are so abundant as to form shell breccia.

Near the top of the section on Seven Mile Beach the strata become more and more unconsolidated and sandy, the upper layers consisting almost entirely of soft yellow and orange-colored sand. Near the top is a soft, white, chalky layer, from one to six feet thick, which Dr. Lawson considers a volcanic ash.[1]

Stratigraphy.—The section along Seven Mile Beach has a thickness of about 4500 feet; it is not complete, however, but is cut off at the bottom and south end by the great fault which runs from Mussel Rock to Black Mountain. The lower or Transition beds are exposed south of Half Moon Bay, but no way of connecting them with the Seven Mile Beach section was found. Near San Gregorio about 500 feet of strata is exposed.

Distribution.—The Merced series, antedating as it does the upheaval which gives the Santa Cruz Mountains its present topographic position, was probably originally laid down over all or most of the region now occupied by these mountains. Pleistocene movements have preserved the lower deposits, while erosion has removed the strata from the upper parts of the range.

It seems possible that most of the beds in different parts of the state from which older Pliocene fossils have been reported will be found to correspond with this series. Dr. Lawson believes that the one he recently described as the "Wild Cat

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[1] Univ. of Cal., Bull. Dept. Geol., I., 144.

Series"[1] in Humboldt county may be correlated with the Merced series. Thus the fauna reported from Kirker's Pass and Green Valley, Contra Costa county, Santa Rosa and Russian River, Sonoma county, suggests the presence of the Merced series. The formation is fairly well developed at San Fernando, Los Angeles county.

Relations.—Near Santa Cruz the Merced series overlies conformably the Monterey series; the two formations seem to grade into each other at the contact. At a number of places the Merced series lies directly upon the pre-Monterey formation. This may have been due either to transgression of the sea during the Merced period or to erosion during part of one or during both of these periods.

Structure.—The end of the Monterey-Merced period was followed by the movement which elevated the Santa Cruz Mountains, making them again a prominent topographic feature. This movement was largely of the nature of faulting, and the largest fault noticed was the compound one, beginning at Mussel Rock and extending southeast nearly to Black Mountain. Many small faults were noticed; among these the one at Wood's Gulch on Seven Mile Beach has a displacement of nearly 900 feet. These faults have a strike of about southeast and northwest. Another group has the strike nearly due east and west.

As a rule the structure of the Merced and Monterey series shows only gentle folding, but locally, as on Seven Mile Beach and in that neighborhood, the dip becomes almost vertical. The structure along Seven Mile Beach reveals a great monocline, with the dip to the northeast. The other limb of the monocline is to the south in the long exposure at Pillar Point. Thence southward the structure shows gentle undulations until Pescadero Creek is reached. At Point New Year and at Capitola synclines show the presence of the Transition beds of the Merced series.

Correlation.—The Transition beds were principally noted along the coast from Spanishtown southward; also near Stanford

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[1] Univ. of Cal., Bull. Dept. Geol., I., 255.

University, and in the ridge through which is cut the San Fernando tunnel in Los Angeles county.

Fifty-two species of fossils were found in the coast area of which eighteen are not known living, and four are not known in the present fauna of the same region. Using the old method of percentages we find 56 per cent. of the fossil fauna in the living fauna. It is found that twenty-two of the forms have been found in strata whose Miocene age is not questioned, of which number five are strictly Miocene. This would place these strata, according to some authorities, in the lower Pliocene; according to others, in the Upper Miocene. We do not as yet feel safe in asserting the identity of any of these species with those found in the Atlantic Miocene. In many cases, however, the resemblance is so strong that for all practical purposes we may assume them to be of the same type, and use them as though we felt sure of their specific identity.

The strata, like the Atlantic Miocene, are characterized by many huge Pectens, large Arcas, and other forms which have no representatives in the present waters of the coast. Thus, there is on the coast of California one very small species of *Arca*, found at San Diego. In these strata we find great numbers of several species of *Arca*, some of which are over four inches broad. The most common of these, the *Arca microdonta*, Conrad, will fit the figure and description of *Arca arata*, Say, of the Maryland Miocene just as well as it does Conrad's figure and description of the west coast species. The presence of the large Pectens, six or seven inches across, gives the fauna a strong resemblance to the Atlantic Miocene of Virginia and Maryland. Aside from the above localities these Pectens have been previously reported only from strata generally recognized as Miocene. The *Crepidula grandis*, Midd, is another form about four times as large as any of its living representatives. Many other interesting forms might be mentioned. It is thus seen that the fauna, while closely related to the living fauna, as shown by the percentages given above, has quite a number of species closely resembling species which, in eastern America, are typical of the Miocene.

In the area near Stanford University the percentage is still lower; out of twenty-five species found only 44 per cent. belong to the living fauna.

On Seven Mile Beach the great thickness of strata gives a good opportunity for the study of faunal changes. Thus the large *Pectens* are limited to the bottom of the series. Of the forms obtained on Seven Mile Beach, *Neptunea tabulata*, *Calyptræa filosa* and *Crepidula prærupta* occur only at the bottom of the section. *Crepidula grandis*, *Arca microdonta*, *Cardium meekianum*, *Saxidomus gibbosus*, *Mactra* (not *Venus*) *pajaroensis* and *Scutella interlineata* disappear at different horizons in about the order named, and are replaced in the uppermost layers by living forms. Thus, for example, the living *Echinarachnius excentricus* replaces *Scutella interlineata; Cardium corbis* replaces *C. meekianum* from which it probably descended.

Of the forms collected on Seven Mile Beach, not including the uppermost beds, thirty-two species have been identified. Of these nine are not known to be living, and five are found only in some other district. Out of thirty-two species in the fossil fauna this gives eighteen, or 57 per cent., in the present fauna of the same region. The character of the fauna is noticeably southern.

The suggestion has been made that the top of the Merced series on Seven Mile Beach extends into the Pleistocene, the fossiliferous strata above what has been called the "upper gasteropod bed" especially having a Pleistocene aspect, as all the forms found in these are still living on the coast. The whole fauna, including the "upper gasteropod bed," gave 81 per cent. of the fossil fauna living in that region.

Not only does the fauna suggest that these upper beds might be considered by themselves, but the structural relations to the lower beds is just obscure enough to prevent a positive assertion that they are conformable. The first writers on the subject regarded them as conformable.

Dynamic movements during the Tertiary.—At the beginning of the Tertiary all the region about the Bay of San Francisco seems to have been slowly sinking and steadily receiving sediment.

This continued until the Miocene. Then the great thickness of sediment yielded to mountain-forming forces. Geologically speaking this movement seems to have been quite rapid, if we may judge from the thorough way that the rocks have been folded, broken and crushed. For a time subaërial erosion was the principal dynamic factor at work in the area of the mountains. Then a slow subsidence set in, and the white shale of the Monterey series was deposited on the coast side of the mountains. In some places what is now the crest of the mountains was covered by the white shale. Then the sediment became sandy, the old mountains which had meanwhile been much eroded settled still more, and the Merced series was laid down. Near San Francisco the conditions were favorable for rapid sedimentation, and nearly a mile of thickness was laid down. Finally at the end of the Pliocene, or beginning of the Pleistocene, movement began along the old axis. Great faults were formed and the center of the range rose, not to its present height, but to a position probably about 1000–1200 feet lower. This left the present flanks of the mountains under water, a fact which doubtless accounts for the preservation there of the soft Merced series.

II. THE PLEISTOCENE HISTORY OF SAN FRANCISCO PENINSULA.

Topography.—The main portion of San Francisco peninsula is occupied by the northern end of the Santa Cruz Mountains and their foothills. The strike of these mountains to the northwest carries them to the seaboard a few miles south of the Golden Gate. In the southern part of the peninsula the mountains are separated from the bay by a broad plain. At the northern end this plain, narrowed down to a valley or windgap of some breadth, separates the mountains from the San Bruno Mountains, a parallel range only a few miles long, and from the irregular groups of hills in the city of San Francisco. On the ocean side of the mountains are remnants of a similar plain. These plains on both sides of the mountains are one of the most marked features of the topography. They usually start quite abruptly from the steeply sloping foothills, at levels varying from 100 to 200 feet above sea level and slope gently toward the bay or sea. On the bay side these extend to the water's edge, and then are continued without change of grade to the center of the bay, then rise as slowly on the other side. On the ocean side wave action has generally cut away the lower part of the slope, leaving cliffs from ten to one hundred feet in height.

Where the contact between this level stretch and the foothills is not parallel with the shore-line or main axis of the mountains it is noticed that the elevation of the contact rises toward the axis of the mountains. In some cases this level seems to be carried up small streams nearly, if not quite, to their heads, forming a marked bench on either bank down through which the streams have recently cut. As some question has been raised as to whether these terraces are not the results of erosion rather than of sedimentation, it may be well to call attention to the evidence more in detail. In the first place, these terraces and fillings show only horizontal bedding; further, the bedding of the strata forming the hillsides is in nearly every case more or less highly inclined; and, finally, in nearly every ravine one or more contacts were found where the horizontal strata can be clearly seen lying upon the highly inclined strata of the Merced series. A few of these might be mentioned. In the head of Wood's Gulch and in the ravine which heads near it a few yards below the Old San Pedro-Colma road, the Merced sandstones and thin-bedded gravels have an almost perpendicular dip. On the edges of these perpendicular beds lie the horizontal Quaternary strata, which may be traced continuously down the ravine to a point near the crossing of the New San Pedro-Colma road; here are found many horizontal pines imbedded in the strata. In the cut just north of the Happy Valley House the horizontal Pleistocene overlies strata of the Merced series, having a dip of 35° N. 20° E.

A study of the neighborhood of San Francisco Bay points to a recent elevation of the mountains to a level much higher than their present. Such a study, as recently pointed out by Professor

Lawson,[1] shows the strong resemblance of San Francisco Bay, of Rodeo Lagoon, Tomales Bay, Walker's Creek, Drake's Bay, Ballenas Bay, the Valley of Lake Merced, etc., to sunken and submerged valleys.

There is another topographic feature which must not be overlooked. Standing upon the hills near South San Francisco station where a comprehensive view can be obtained of the line of hills extending from Seven Mile Beach to Redwood City their summits can be seen to present a remarkably even horizontal line. Examined on the ground the top of this line of hills has the aspect of a dissected plateau, from which rise a few sharply conical knobs. These have the appearance of remnants left by the eroding waters which planed off the top of the hills.

Dr. Lawson has also pointed out that the whole coast has recently stood for a considerable time at an elevation of 1600 to 2100 feet below its present level.[2] Evidence of this is seen in the level summit of the main ridge to the north of Black Mountains.

The deposits.—Turning to the deposits we find three distinct sets exclusive of those now forming.

Of the first only remnants remain. They are the deposits corresponding with the topographic features last mentioned. All along the level summit of the foothills no deposits are noticed until Black Mountain is approached; then the summits of the foothills are more or less covered with water-worn bowlders of metamorphic rocks. Bowlders do not occur further north, probably because in that direction the foothills are separated from the main ridge of the mountains by the long deep valleys of Bear Creek, Crystal Springs, and San Andreas, while near Black Mountain the foothills are connected with the mountains which must have supplied all such material.

The second class of deposits are stream and wind deposits. These are quite prominent in the benches in the streams. They appear as sand dunes on the ocean side of the mountains buried

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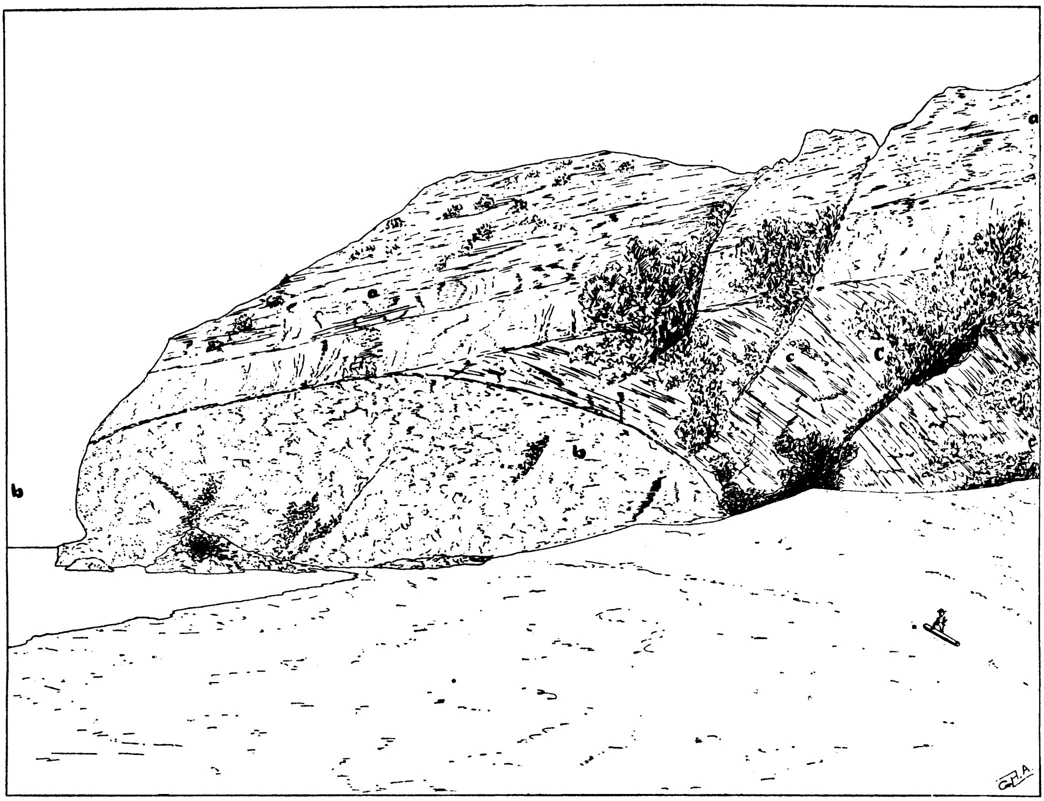
[1] Univ. of Cal., Bull. Dept. of Geol., I., 263.

[2] Univ. of Cal., Bull. Dept. Geol., I., 115-160.



Mussel Rock from the South, showing marine Pleistocene (*a*), overlying sand dunes (*c*), and igneous rocks (*b*).

below marine deposits of later date. (See Plate X.) They make up a considerable portion of the level plain surrounding the bay as shown by recent stream cuttings. These deposits have yielded remains of the mammoth or mastodon, and in the deposits in the various streams running to the bay are found a large number of trunks and cones of conifers, sometimes four feet in diameter.

The third class are recent marine deposits. On the ocean side these are very marked, forming the top of the level benches described and having a thickness in the sea-cliffs of from five to fifty feet, in one place just south of Mussel Rock, having a thickness of over 200 feet. In some places, as near Monterey lighthouse, the beds are only a foot or two thick, and are made up of black earth, rocks, and abalone shells in great numbers. On the bay side of the mountains the surface of the broad valley plain and stream benches is the result of marine erosion and deposition. The deposits there are seldom more than a foot or two thick. Here are also found large areas of black earth full of rocks and shells.

History.—The interpretation of these data would seem to be as follows:

1. A period of erosion with the mountains about 1800 feet below their present level. This may have been the final position of the mountains at the end of the post-Merced movement, or the mountains may have shifted to this position soon after During this time the most of the soft Merced series above the water line seems to have been removed, the water acting as a protection to the deposits which now fringe the base of the mountains.

2. A period during which the mountains stood about 1200 feet higher than during the first period, or about 600 feet below their present level. This produced the marked bench or plateau forming the summit of the foothills.

3. A period during which the region stood, according to Professor Lawson,[1] nearly 400 feet higher than at present. San Francisco Bay was a broad valley and the islands stood up as

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[1] Univ. of Cal., Bull. Dept. of Geol., I., 267.

prominent hills. Conifers were abundant over parts of the area now treeless.

4. A period of subsidence. Tide-water entered the Golden Gate, filled San Francisco Bay, then spread out over the Santa Clara valley to the foothills. The whole region to the foothills was reduced by erosion and deposition to a level. The waters extended up many of the streams. San Francisco was a little cluster of islands. Considerable deposits were laid down upon the ocean-side of the peninsula.

5. A period of uplift to present level. One of the most interesting features of the last period is the remarkable erosion which has taken place in the deposits laid down in the periods just preceding. The topographic changes caused by erosion in the last twenty-five years have been so marked that, judging by the evidence of erosion in these latest beds previous to 1869, we must conclude, either that these beds have been subjected to erosion a very short time or that climatic or other conditions have become more favorable for erosion of later years. Quite a large number of hollows through which ran in 1869 county or farm roads now present impassable gullies, twenty-five to seventy-five feet deep.

III. THE AGE OF THE COAST RANGES.

A casual examination of a topographic map of California reveals a lack of unity between the northern and southern Coast Ranges as regards their strike and the apparent direction of folding. The ranges occupying the coastal region of central California have a very uniform strike of northwest and southeast, suggesting a certain unity in the time and manner of their uplift. In Santa Barbara County we come abruptly upon a series of ranges running nearly east and west through Santa Barbara, Ventura and Los Angeles counties. These ranges seem to possess a certain unity in having been elevated together. Was the movement synchronous with the elevation of the ranges further north ? A comparative study of one of the ranges of each group can hardly be taken as conclusive of the groups of ranges as a whole, but will be suggestive of what may be true of all.

The age of the Santa Cruz Mountains can with little question be placed at the end of the Merced period. Unfortunately, we are not as yet able to say exactly what is the age of the topmost beds of the Merced series. The highest beds from which fossils were obtained gave a small fauna, all of whose forms are living on the coast today, thus seeming to be of Pleistocene age. Including the fossiliferous beds which occur a few feet further down, and which must be included with the top beds, the fossil fauna shows 81 per cent. of living forms, thus seeming to be of Pliocene age. The most that can be said is that the post-Merced uplift occurred just about the end of the Pliocene or early in the Pleistocene. In either case these Coast Ranges of California are among the youngest mountain ranges of any prominence in the world.

Turning to the San Fernando Range, we find the topmost beds concerned in the uplift and folding of the range correspond with the lower or transitional beds of the Merced period, thus placing their age about the end of the Miocene or beginning of the Pliocene.

Further confirmation of this is found in a study of the horizontal fossiliferous deposits along the coast, as at Santa Barbara, San Pedro, San Diego, etc. Thus, at San Pedro in Los Angeles county, there is found first the shales of the Monterey series dipping south. Above them unconformably come first a little sand dune or wind deposit, then a few feet of quite fossiliferous sand, then a top fossiliferous layer.

The top layer is unquestionably Pleistocene. A study was made of the fossiliferous layer just below. Altogether 125–150 species were collected in this layer, of which number 104 species have been determined. Of the 104 species identified 99 or 95 per cent. are known living. But many of those living are only known now in, for example, the Arctic fauna. Thus it is found that of the 104 species twenty-six have not been reported from the coast near San Pedro, leaving seventy-eight species of 104 fossil species known to be living, or 75 per cent.

Again it is noticed that of the species which have migrated all but two have gone northward, a number being known only in Arctic waters at present.

A percentage comparison of the fauna of these beds with the present fauna of that part of the coast would make the beds Pliocene. A consideration of the Arctic character of the fauna would place them near the end of the Pliocene or the beginning of the Pleistocene. In any case they probably do not differ greatly in age from the beds which form the top of the Merced series in the Santa Cruz Mountains.

If these observations and their interpretations have been correct this will make the age of the east and west ranges of Santa Barbara, Ventura, and Los Angeles counties near the beginning of the Merced period or about the end of the Miocene; while the ranges to the north were elevated at the end of the Merced period or near the end of the Pliocene.

IV ON THE RECENT HISTORY OF SANTA CATALINA ISLAND

The finding of a species living which had been supposed to be extinct, or which if not extinct had long since been forced by changing conditions to migrate to some other region, has always had a peculiar interest to the student of biology or geology. Still more interest attaches to the finding of a fauna which belonged to a bygone age, and especially when the record of events is sufficiently clear to give a plausible reason for the presence of the older fauna. Such a condition of things seems to exist on Santa Catalina Island today.

In the preceding study attention was called to the existence at San Pedro, and other points, of beds containing an abundant fossil fauna of probably Pliocene age. The two fossiliferous beds at San Pedro were deposited during a submergence of all the coastal region, the lower or Pliocene beds having preceded the submergence, the upper beds having been laid near the end of the elevation which followed. This movement shows most clearly in the topographic features of the coastal region of southern California. Everywhere near the coast is evidence of a recent submergence to a depth of from 1200 to 1500 feet. The long stretches of plains and level benches, the old cliffs marking the advance of wave action, the stream topography which within those levels seems to be just taking a new start, are all evidence of the same fact.

Santa Catalina Island is a large island lying about twenty miles south of San Pedro. A short time since Professor Lawson called attention to the fact that Santa Catalina Island had not shared in the general depression which had submerged the other islands and coastal regions.[1] He pointed out that the island shows no shore lines, no benches, no levels of erosion. The stream basins are all of considerable age, having deep, rugged valleys, and the sharp edges of the separating ridges are typical of subaërial erosion long continued.

We find, then, that the conditions have remained constant here since the time when the Pliocene beds were being deposited over on the mainland. It will be of interest then to compare the present fauna of Santa Catalina Island with the fauna living now on the coast of San Pedro, and also with the fossil fauna found at the same place.

By a study of Dr. Cooper's list of Californian fossils, 1888, we find that five otherwise extinct species from the Pliocene or Quaternary of Santa Barbara, San Pedro, and San Diego are still living on the island: *Amycla undata*, Carpenter; *Daphnella clathrata*, Gabb; *Nassa insculpta*, Carpenter; *Psephis salmonea*, Carpenter; *Solarellia peramabilis*, Carpenter. There are also found living on the island, and fossil on the mainland, one species, *Cryptodon flexuosus*, Montagu, known elsewhere only in the North Atlantic; one, *Lucina borealis*, Linnaeus, known elsewhere only in Arctic waters; one, *Laqueus californicus*, Koch, known elsewhere only in the North Pacific. In addition to these, thirteen species—*Bittium asperum*, Gabb; *Callista newcombiana*, Gabb; *Cardium centifilosum*, Carpenter; *Chrysodomus tabulatus*, Baird; *Diala acuta*, Carpenter; *Leptothyra bacula*, Carpenter; *Lucina tenuisculpta*, Carpenter; *Lunatia pallida*, Broderip and Sowerby;

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[1] Univ. of Cal., Bull. Dept. Geol., I., 138.

Margarita pupilla, Gould—which are found on or about Santa Catalina Island are only known elsewhere on the coast to the north; while it forms the northern limit of four species, *Chorus belcheri,* Hinds; *Nucula exigua,* Sowerby; *Omphalius fuscescens,* Philippi; *Ostrea conchaphila,* Carpenter.

These facts indicate that fauna of Catalina Island has been little affected during a time when many species on the mainland have become extinct and others forced to migrate. The fauna is largely northern, though possessing a few southern forms. It thus resembles quite strongly the fauna studied at San Pedro and called in this paper Pliocene.

This case is interesting, not alone from showing that the fauna considered Pliocene on the coast of the mainland is still living on or about the island, but from the way the deductions made from the topography and from the fauna support each other.

GEORGE H. ASHLEY.

STOCKTON, CAL.,
April 6, 1895.